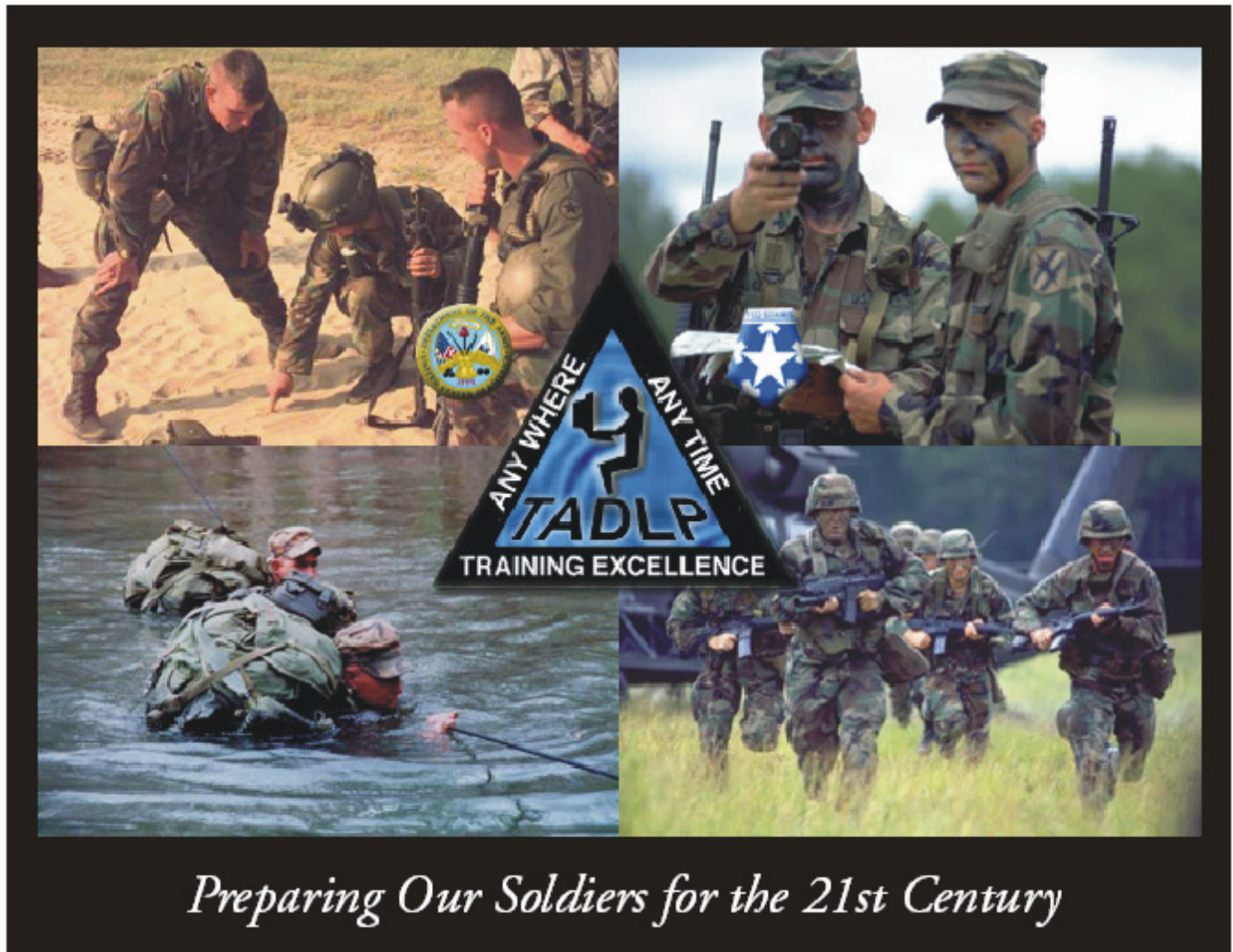


THE ARMY DISTANCE LEARNING PROGRAM



Bandwidth Study

Version 1.0

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OFFICE OF THE PROJECT MANAGER
THE ARMY DISTANCE LEARNING PROGRAM

White Paper TADLP Bandwidth Study

1. Purpose: The purpose of this white paper is to provide an analysis of the bandwidth that will be required for Phase II of the TADLP.

2. Background:

- a. Total Army Distance Learning Program (TADLP). TADLP Phase II will deliver a system that will require communications links connecting classrooms and file servers. The system will be used to train soldiers at their duty station instead of sending them to a service school. The communications links will use both existing and emerging communications technology, and will provide standardized training to forces where needed, when needed using multimedia technology in accordance with the TADLP Operational Requirements Document (ORD), reference (a) (see appendix A, References).
- b. Bandwidth. To use existing networks, bandwidth must be purchased by TADLP; it is purchased in units of Megabits per second (Mbps), a measure of the rate at which data is transmitted. A transmission line capability is specified in Mbps as to its' ability to transmit digital data. Classroom instructional media bandwidth requirements can be specified in Mbps as a digital data load. TADLP funding is limited to 3 Mbps per classroom at a cost of \$285 per Mbps of transmission bandwidth. Additionally, installation Campus Area Networks (CAN) are limited in the amount of additional load they can accommodate. Bandwidth limitations are an identified risk for TADLP.
- c. Two types of bandwidth estimates are considered:

“Peak” Bandwidth is the instantaneous maximum bandwidth required by a TADLP classroom. It is the bandwidth required to guarantee no delay and no degradation in the received data.

“Expected” Bandwidth is, for this study, the bandwidth required over a given timeframe for an average simultaneous mix of courseware, collaboration, simulation, and network overhead and administrative data for a hypothetical classroom. It is the bandwidth that TADLP expects to buy.

- d. Other Studies. Three additional studies were conducted prior to this study. They were conducted by TRADOC DCSIM {reference (b)}, ISEC {reference (c)}, and TRAC {reference (d)}, and provided estimates of expected bandwidth. None of the studies incorporate the refined user requirements of the TADLP Issues Package {reference (e)}. The prior studies are reviewed and summarized in appendix B.

3. Analysis:

A summary of the analysis to determine the peak and the expected bandwidth is provided below.

- a. Peak Bandwidth. Peak Bandwidth is estimated as 36.8 Mbps per classroom. For this estimate, the following scenario was assumed:

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- (1) All 17 workstations in an active component classroom simultaneously require Interactive Machine Instruction (IMI) courseware to provide streaming video (the MPEG1 standard of 1.5 Mbps is assumed),
- (2) The streaming video is received simultaneously with either VTT (H.320 at 384Kbps) OR video collaboration (also at 384 Kbps).
- (3) 15% network and administrative bandwidth is added to each of (1) and (2).

The scenario and calculation for Peak Bandwidth is illustrated by figure 1:

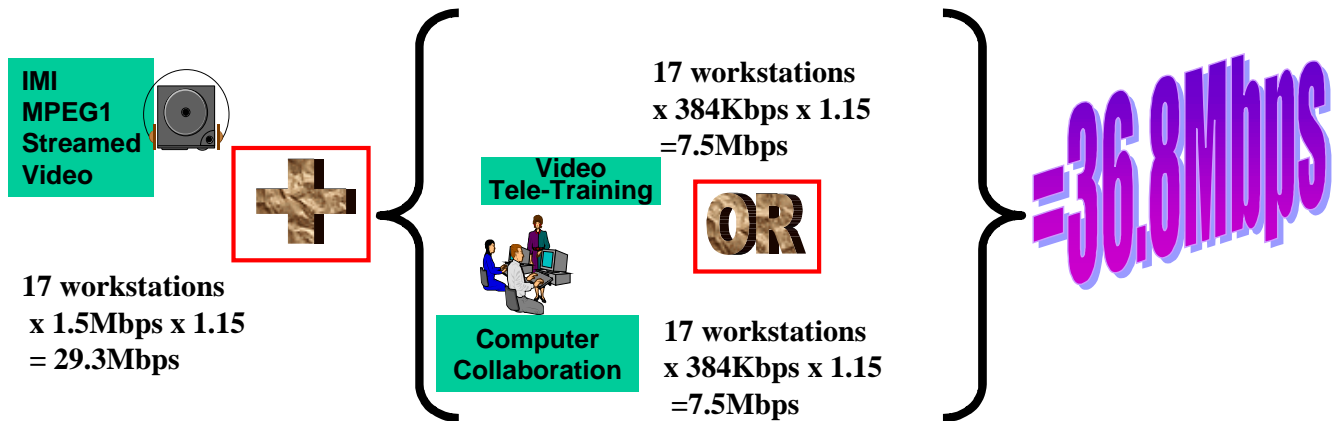


Figure 1. Peak Bandwidth

- b. Expected Bandwidth. In this study, Expected Bandwidth, is estimated as 5 Mbps per classroom. This was determined as follows:

- (1) Using the requirements of the ORD, the five functions that will be used to deliver training in support of a distance learning classroom were determined (see Appendix C for additional detail regarding the functions):
 - (a) Courseware
 - (b) Collaboration
 - (c) Simulation
 - (d) Administration and Network Overhead
 - (e) VTT

The content of these five functions can be broken down into four media types: text, VTT, images, and streaming video. Expected Bandwidth is defined in terms of the data load imposed by the average use of the media types.

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(2) The percentages of the four media types were determined using the first 35 courses developed for the TADLP. Media Content Percentages are weighted by course hours. Figure 2. Shows media type usage expressed as a percentage.

Of the four media types that make up the courseware, VTT has a dedicated communications link and so is not part of the Expected Bandwidth estimate.

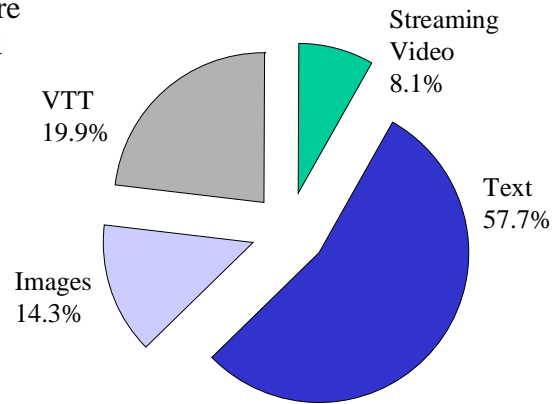


Figure 2. Media Content Percentages

See Appendix D for additional detail and a spreadsheet for this calculation.

(3) The bandwidth contributions of the media types (text, images and streaming video) were calculated using:

$$\text{media bandwidth contribution} = (\text{media content percentage}) \times (\text{media bandwidth}).$$

(4) The media bandwidth contributions were then summed to provide the total bandwidth, and 15% of the streaming video and still picture media bandwidth contributions were added to account for Network and Administrative Overhead.

The results are shown in table 1:

Table 1. Expected Bandwidth

| Type Media | Media Bandwidth | Media Percentage (as a decimal fraction) | Media Contribution to Bandwidth (per Classroom) |
|--|--------------------|--|---|
| Text | 0.056 Mbps | (x 0.58 =) | 0.550 Mbps |
| Images | 0.8 Mbps | (x 0.14 =) | 1.941 Mbps |
| Streaming Video | 1.5 Mbps | (x 0.08 =) | 2.074 Mbps |
| “Admin/Network Overhead” @ 15% of stills and video | | | <u>0.602 Mbps</u> |
| total | | | 5.167 Mbps |
| | | | <u>≅ 5 Mbps</u> |

See appendix E for additional detail and a spreadsheet for this calculation.

c. Results Of Other Studies.

(1) Other studies were conducted by TRADOC DCSIM, TRAC, and ISEC. The results are shown in table 2:

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Table 2. Results of Other Studies.

| Who | Workstations per Site | Classrooms per Site | Workstations per Classroom | Expected Bandwidth per Classroom (Mbps) |
|-------------|-----------------------|---------------------|----------------------------|---|
| DSCIM | 48 | 3 | 16 | 4.56 |
| TRAC | 48 | 3 | 16 | 4.56 |
| ISEC – Avg. | 51 | 3 | 17 | 2.75 |

(2) All of the above studies:

- (a) consider media types, and media content percentages
- (b) determine and sum media contribution to bandwidth
- (c) calculate only expected bandwidth
- (d) did not calculate peak bandwidth

(3) Differences between this study and the other studies are as follows:

(a) DCSIM study {Reference (b)}:

- (1) does not include network and administrative overhead (which was @ 0.5 Mbps)
- (2) assumes slightly different values for the media percentages (an analysis of percentage of each media type in the courseware was not available when the study was done)
- (3) assumes that only 90% of the workstations will be in use at a given time
- (4) uses 16 instead of 17 workstations per classroom

(b) TRAC study {Reference (c)}:

- (1) does not include network and administrative overhead (which was @ 0.5 Mbps)
- (2) assumes different values for the media percentages (an analysis of percentage of each media type in the courseware was not available when the study was done)
- (3) is derived from sketchy information as to how data was calculated.
- (4) Uses 16 instead of 17 workstations per classroom

(c) ISEC study {Reference (d)}:

- (1) includes network and administrative overhead at 3% (which is not supported by the TADLP Telecommunications Plan, Reference (f)).
- (2) may assume different values for the media percentages (they were not stated)
- (3) used constructed messages in the simulation which may have differed from the actual construction of the data that they represent.
- (4) is derived from sketchy information as to how data was calculated
- (5) did not define “average” use
- (6) is based on a specific architecture

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4. Conclusions.

- a. The TADLP study results are compared with other studies in table 3:

| Who | Workstations per Classroom | Expected Bandwidth per Classroom (Mbps) |
|-------------|----------------------------|---|
| TADLP | 17 | 5.12 |
| DSCIM | 16 | 4.56 |
| TRAC | 16 | 4.56 |
| ISEC – Avg. | 17 | 2.75 |

Table 3. Study Comparison.

- b. The statistics for the data shown in table 3 are as follows: Avg. of studies = 4.23 Mbps; Mode = 4.56; Median = 4.56; Standard Deviation = 1.01. Using two standard deviations and assuming a normal distribution, for the probable range of Expected Bandwidth, it can be predicted with 95% certainty that Expected Bandwidth will be within the range of 3 to 7 Mbps.
- c. Analysis of the courseware content, by media type, is a valid method of predicting required bandwidth. The results of the TADLP study compare favorably with other studies, especially when differences in methodology and values used are considered.
- d. The Expected Bandwidth required for a single TADLP classroom is approximately 5 Mbps (other studies used the term “average” bandwidth). Peak and Expected Bandwidth are measured at the connection between the TADLP LAN and the outside world (CAN/WAN) and are affected most by:
- (1) the number of workstations in use,
 - (2) the location of the courseware relative to the connection between the LAN and the WAN,
 - (3) the amount of Network and Administrative overhead,
 - (4) the percentages and bandwidths of each type of media used in the courseware.
- e. TADLP Bandwidth estimates are affected by assumptions, such as the number of workstations, and architecture. For example, if the courseware is resident on the classroom LAN, there is no need to download it through the CAN or WAN; in this case, courseware downloading does not add to the Expected Bandwidth. This study assumes:
- (1) 100% of 17 workstations per classroom are in use,
 - (2) the courseware is not hosted on a classroom LAN server,
 - (3) overhead is 15% of MPEG1 video and still picture bandwidth
 - (4) the Courseware Media Content Percentages derived for the first 35 TADLP courses are representative of the rest of the courses.
 - (5) still picture bandwidth is 800 Kbps

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- f. A Peak Bandwidth requirement of 36.8 Mbps per classroom may degrade services on the CAN and WAN to which a classroom is connected.

5. Recommendations:

Measures must be taken to reduce the risk that a large Peak Bandwidth will pose to the CAN/WAN. Measures must also be taken to reduce Expected Bandwidth to within that funded for TADLP.

Appendix A References

- (a) TADLP ORD, 7 Oct 97
- (b) ODCSIM Project Officer memo (undated), subject: “Communication Infrastructure Briefing to the TPIO and PM ADLP, 26 Feb 98, 1330-1430 hrs, DCST Bldg. 161, Collins Conference Room”
- (c) TRADOC Network Requirements Study, 19 Feb 98; TRAC, FY97 TRADOC AR5-5 Study Program (POC is Mr. Howard Haeker). Modified by e-mail from the POC on 6 and 8 May 1998.
- (d) ISEC Bandwidth study, Nov 97 and Mar 98
- (e) TADLP Issues Package, 18 May 1998
- (f) Telecommunications Engineering Plan for Army Distance Learning System, Draft ver 1.0, 30 Sep 97, TR No. AMSEL-IE-IS-97516, ISEC, Ft Huachuca, AZ
- (g) TADLP Architecture Instructional View, 17 April 1998
- (h) PMTADLP Briefing to PEO-STAMIS, 21 May 1998

Appendix B

Results of Prior Studies

1.0 DCSIM Study: The following is an interpretation of the DCSIM Study.

1.1 Method:

The DCSIM study {Reference (b)} used “worst”, “best” and “expected” values for various factors for TADLP requirements. It estimated expected bandwidth for “incoming” classroom support, and assumed a courseware server at a place outside the LAN. It also estimated “outgoing” bandwidth for the server. DCSIM indicated an intention to proceed using the “expected” values, shown in boldface in figure 1.

1.2 Assumptions: The assumptions below are from the expected case spreadsheet in reference (b):

1.2.1 MPEG I at 1.5 Mb/s

1.2.2 Even distribution of requirements (probably not valid)

1.2.3 VTT at 384 kb/s. (H.320)

1.2.4 Other factors as stated (see also figure 1. for the values used):

1.2.4.1 Usage Factor: That fraction of the workstations which, on average, are occupied.

1.2.4.2 Intra-post factor: That fraction of traffic which goes to the local DTAC. (Shown in figure 1., but does not apply to a classroom)

1.2.4.3 Streamed Video Factor: The fraction of total courseware which is to be streamed video.

1.2.4.4 Advance Notice factor: The proportion of the streamed video which can be scheduled (downloaded) in advance.

1.2.4.5 Multi-Cast factor: That fraction of the total requirement which can be reduced by multi-casting.

1.2.4.6 VTT factor: The fraction of total courseware which is to be VTT.

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1.3 Equation: The equation for Expected Bandwidth is derived using figure 1.:

$$(B7 * C7 * D7) * (1-E7) * \{F7 * G7 * (1-H7) * (1-I7) + J7 * K7\} = \text{Expected Bandwidth}$$

| | A | B | C | D | E | F | G | H | I | J | K | L |
|----|---------------|----------|--------|--------------|-------------------|------------------|-----------------------|-----------------------|-------------------|-----------------|------------|---------------------------|
| 5 | Facility Type | Fac/Inst | WS/Fac | Usage Factor | Intra-post Factor | MPEG Rate (Mb/s) | Streamed Video Factor | Advance Notice Factor | Multi-Cast Factor | VTT Rate (Mb/s) | VTT Factor | Bandwidth required (Mb/s) |
| 6 | | | | | | | | | | | | |
| 7 | DL CR | 3 | 16 | 0.9 | 0 | 1.5 | 0.2 | 0.2 | 0 | 0.384 | 0.2 | 13.68576 |
| 10 | | | | | | | | | | | | |

Workstations
in use per site

Fraction of the
courseware that is
streamed video

Fraction of
courseware
which can be
downloaded
in advance

Fraction of
students working
synchronously

Fraction of the
courseware that
is VTT

Figure 1. 1st DCSIM Study (expected values)

1.4 Results:

The DCSIM study estimated an expected bandwidth of 13.69 Mbps per site for the total of computer and VTT bandwidth for a site containing three classrooms of 16 workstations per classroom. This equates to about 4.56 Mbps per classroom.

2.0 TRAC conducted TRADOC Network Requirements Study (TRADOC NRS): The following is an interpretation of the TRAC Study.

2.1 Method:

The TRAC study {Reference (c)} provides a Rough Order of Magnitude estimate for VTT and CD-ROM instruction for TRADOC sites only. The author has acknowledged that the results of the TRAC study are a first cut using old data, and should no longer be considered valid {see reference (c)}.

2.2 Assumptions:

Assumptions were not stated. Clarification was provided in an update to reference (c) that the following factors were used:

Appendix B

Results of Prior Studies

| Nr. of workstations | % in use | % which will use streamed video | %downloaded in advance |
|------------------------|-------------|------------------------------------|---------------------------|
| 16 | .9 (90%) | .2 (20%) | .2 (20%) |

Values of 1.5 Mbps for MPEG streaming video (MPEG1 rate) and 384 Kbps for VTT (“studio VTC”) were used. The “multicast” and “intra-post” factors used in the DCSIM study were assumed to be zero in the TRAC study.

2.3 Equation:

The exact equation used to develop the estimated bandwidth could not be determined from the information provided. An update to reference (c) noted that the media bandwidth contributions were summed to provide the result.

2.4 Results:

The Expected Bandwidth as stated in reference (c) is: “5 Mbps/site - 3 classrooms per site” and “1.5 Mbps for CD-ROM per classroom” and “1.5 Mbps for VTC per classroom”. A revised estimate was stated in an email update to reference (c) as “4.56 (Mbps) / DL classroom

3.0 ISEC Study: The following is an interpretation of the ISEC Study.

3.1 Method:

The ISEC study {Reference (d)} estimated the Media Contributions to Bandwidth. This was used to form a model of data traffic, as a means of placing a load (simulating the flow of data, e.g. courseware) on a simulated communications circuit. ISEC used modeling software and a specific architecture to simulate the flow of the data traffic. The load imposed by the data traffic was observed based on known, and assumed factors and the percent use of the communications circuit was measured. The estimate of the Expected Bandwidth was derived from the percent use of the communications circuit and the size of the circuit.

3.1.1 Data Traffic:

Data traffic flowing through a communications circuit in a given amount of time was constructed by dividing the traffic into media types (i.e. streaming video, etc.), and estimating the contribution of each to the total.

3.1.2 Simulation:

To allow modeling using COMNET III, a specific architecture including a “large enough” communications circuit was assumed. The communications circuit was sized for no (≤ 10 millisecond) delay in the data traffic.

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Results of Prior Studies

Simulation of the data traffic was conducted for both a 30 classroom site and a three classroom site, chosen to represent extremes of the classroom site sizes. The percent utilization of the “large enough” communications circuit was recorded and used to provide an estimate of the Expected Bandwidth.

3.1.3 Architecture:

The simulation assumed a specific design; it is invalid for other designs.

3.2 Assumptions:

The assumptions stated directly for the study are provided in Attachment 1. A summation of the assumptions used by the ISEC study is provided below:

3.2.1 Data Traffic:

The equation and factors used to model the data traffic were poorly stated. The following paragraphs represent what was stated regarding data traffic.

- 3.2.1.1 “Average message size was calculated from data on MOA Courseware. (Data for some classes was not used because of incomplete and / or inconsistent data.)”
- 3.2.1.2 “A consistent procedure was used to calculate the total data traffic generated during the total duration of the class for each class. Then an average for all classes, weighted for class distance learning duration, was calculated.”
- 3.2.1.3 “Traffic originates at the server(s) and terminates at the classroom(s)”
- 3.2.1.4 “Worst case traffic will result from all workstations simultaneously receiving MPEG1 video messages from their video server at a frequency of no less than one message per second.”
- 3.2.1.5 The percentages of data traffic were considered in terms of contributors to the total as discussed below:
 - 3.2.1.5.1 “Videotape was taken to represent MPEG1 video.”
 - 3.2.1.5.2 “IMI was split into 90% non traffic generating and 10% using MPEG1 video”
 - 3.2.1.5.3 “Video Tele - Training (VTT) data rate was 384 Kbps.”
 - 3.2.1.5.4 “Internet access was taken to represent full time use of the Internet at an empirically determined rate. The rate was taken from a study of server utilization at Fort Eustis by Neal Nelson & Associates. The average bandwidth per hour over a four day period was 101.82 MBytes / Hr.”
 - 3.2.1.5.5 “Printed courseware was ignored.”
 - 3.2.1.5.6 Network System Management (NSM) traffic is accounted for by adding 3% of the total of all other traffic.
- 3.2.1.6 Time Length: “Weeks were assumed to be five days, eight hours per day.”

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3.2.2 Simulation of Media Types:

“The message size for each message sent during the simulation run was varied as well as the interval between messages to simulate data traffic flow for the various types of media.”

3.2.3 Hardware and Architecture:

3.2.3.1 The model of the data assumed a central server architecture: “All data traffic passes one way through one communications circuit. The server(s) will be on one side of this circuit and the workstation(s) will be on the other side.”.

3.2.3.2 Hardware was selected using the System Design Description

3.2.3.3 “Two models, one with 51 users and one with 540 users, were assumed to accurately represent the extrema of the configurations that will be fielded.” (not valid- ignores the single classroom site)

3.2.3.4 Additional assumptions regarding the architecture (called “Abstractions” in Reference c.) are, for simplification, provided in Attachment 1. A high level summary is provided below:

3.2.3.4.1 The model was modified so that there would be no restriction of data traffic to or from the one communications circuit of interest.

3.2.3.4.2 The actual data traffic can be simulated by messages with a frequency as low as ten per second.

3.3 Equation:

Both Data Traffic Rate and Expected Bandwidth were are discussed below. Data Traffic Rate is the name given here to label the data rate used in the simulation.

3.3.1 Data Traffic Rate:

The Data Traffic Rate was used to construct the message size(s) and intervals used for the simulation. The below equation for the data traffic rate used for the simulation is derived from the description of the construction of the message size and interval for the simulation.

$$\begin{aligned} \text{Data Traffic Rate} = & \frac{(\text{videotape rate}) * (\text{videotape duration})}{(\text{duration of all classes})} \\ & + \frac{(\text{VTT rate}) * (\text{VTT duration})}{(\text{duration of all classes})} \\ & + \frac{(\text{MPEG1 IMI rate}) * (\text{MPEG1 IMI duration})}{(\text{duration of all classes})} \end{aligned}$$

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$$+ \frac{(\text{Internet rate}) * (\text{Internet duration})}{(\text{duration of all classes})}$$

Note: non-MPEG1 IMI data was ignored in calculating Data Traffic Rate.

3.3.2 Expected Bandwidth:

The ISEC study simulation determined that a certain size communications circuit was used to a certain fraction of capacity; it did not directly determine Expected Bandwidth.

The percent use of the communications circuit (determined from the simulation) and the communications circuit size can be multiplied as a means of providing an estimate of the Expected Bandwidth. In actual practice, this method will be used to determine when additional bandwidth must be purchased. The resulting equation is:

$$(\text{communications circuit size}) \times (\text{percent use}) = \text{Expected Bandwidth}$$

3.4 Results:

3.4.1 Site with 51 workstations:

The ISEC model estimated a requirement to use from 5.3% (average use) to 52.6% (heavy use) of a 155.52 Mbps (OC3) line per site for computer bandwidth only for a site containing 51 workstations.

This equates to 8.24 to 82.4 Mbps per 51 workstation site, 2.75 to 27.5 Mbps for a 17 workstation classroom, or 0.161 to 1.613 Mbps per workstation.

3.4.2 Site with 540 workstations:

The ISEC study estimated a requirement to use from 7% (average use) to 69.38% (heavy use) of a 1244.16 Mbps (OC24) line for bandwidth for a server providing courseware to 540 workstations.

This equates to a bandwidth requirement of 87.1 to 871 Mbps per 540 workstation site, or 2.74 Mbps to 27.4 Mbps for a 17 workstation classroom, or 0.161 to 1.613 Mbps per workstation (the same per workstation as the 51 workstation model).

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4.0 Summary of Prior Studies:

4.1 Classes of Data:

All of the previous studies considered media content percentage, (e.g. for streaming video, etc.), and sum them in terms of the media contribution to bandwidth to provide an estimate of the Expected Bandwidth (either directly or indirectly).

4.2 Additional Factors:

Each study contributed factors for the development of a more comprehensive Expected Bandwidth model. Each study ignores or assumes away at least some factors.

4.3 Assumptions:

Assumptions used in previous studies were used or modified to assist in developing the assumptions for this study. Assumptions vary as to percentages, media bandwidths and system architecture.

4.4 Simulation:

The ISEC use of simulation to refine the bandwidth estimate was not necessarily an asset. The simulation did not consider the TADLP specific architecture.

4.5 Results and Comparison:

4.5.1 A table showing the results of the studies is shown as Table 1:

Table 1. Results of Prior Studies

| Who | WS/Site | CR/Site | WS/CR | Line Size (ISEC study) | Line Use % | BW/ Site (Mbps) | BW/ CR (Mbps) |
|-------------|---------|---------|-------|------------------------------|---------------|-----------------------|---------------------|
| DSCIM | 48 | 3 | 16 | NA | NA | 13.69 | 4.56 |
| TRAC | 48 | 3 | 16 | NA | NA | 13.69 | 4.56 |
| ISEC – Avg. | 51 | 3 | 17 | OC3 | 5.3 | 8.24 | 2.75 |
| ISEC – Hvy | 51 | 3 | 17 | OC3 | 52.6 | 82.4 | 27.5 |
| ISEC – Avg. | 540 | 36 | 15 | OC12 | 7 | 87.1 | 2.42 |
| ISEC – Hvy | 540 | 36 | 15 | OC12 | 69.38 | 871 | 24.2 |

4.5.2 The differences between the results may be further considered by looking at the Prior Study Assumptions shown in Table 2.:

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Table 2. Prior Study Factors

| Factor | DCSIM (expected case) | TRAC | ISEC |
|--------------------------|--------------------------|-------------------|-----------------------|
| Workstations in use | $0.9 * 16 = 14.4$ | $0.9 * 16 = 14.4$ | 17 |
| 1-IntraPost Factor | 1 | 1 | 1(not used) |
| MPEG1 rate | 1.5 | 1.5 | 1.5 |
| MPEG1 % | 20% | 20% | 10% or 20% * |
| 1-Advance Notice Factor | 0.8 | 0.8 | 1(not used) |
| 1- Multicast Factor | 1 | 1 | 1 |
| VTT rate | 384bps | 384bps | 384bps |
| VTT % | 20% | 20% | 100% |
| Videotape rate | 0 | 0 | 1.5Mbps |
| Videotape % | 0% | 0% | Not stated |
| non video streaming load | 0 | 0 | 0 |
| Internet load | 0 | 0 | 226Kbps (101.82MB/hr) |
| Network System overhead | 0% | 0% | 3% |

* Reference c., Appendix C “Description of Calculations” says 20%; Reference c, “Assumptions” says 10%. It is reasonably apparent that 10% was used.

5.0 Conclusions:

5.1 All of the studies {see appendix A, references (b) through (d)} supported the idea, either directly or indirectly, that a local courseware server could be used to minimize WAN bandwidth.

Appendix B Results of Prior Studies

Attachment 1 to Appendix B ISEC Study Assumptions

The “abstractions” and assumptions used in the ISEC study are quoted below for reference. No validation is implied and none was attempted. To ease comparisons with the actual ISEC study, an attempt to minimize any changes in formatting has been made.

1.0 Abstractions:

The following “abstractions” were used to facilitate the simulation:

- The 51-user model uses some different naming conventions than the 540-user model. The names used below are those in the 540-user version. The modifications below were made to both, except for the post switches, which were not required in the 51-user version.
- The model was modified so that there would be no restriction of data traffic to or from the one communications circuit of interest. (i.e.):
 - = Additional video servers were added, one for each classroom.
 - = Each video server was given it's own 100BaseT Ethernet.
 - = An NSM server was used for each set of three video servers - classrooms.
 - = An infinitely fast server switch was added to combine the output of sets of three 100BaseT Ethernets, which carried the combined traffic of three video servers and the corresponding NSM server.
 - = An infinitely fast post switch was added to combine the output of the server switches listed in the previous sentence.
 - = OC-12 class lines were added to connect the server switches to the post switch mentioned in the previous two sentences.
 - = Workstations were contained within classrooms. Data for each set of three classrooms was apportioned to the classrooms by an infinitely fast building switch.
 - = OC-12 class lines were added to connect the classrooms to the building switch.
 - = Data for the building switches was apportioned among them by an infinitely fast post switch.
 - = OC-12 class lines were added to connect the building switches to the post switch mentioned in the previous two sentences.

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- The actual data traffic can be simulated by messages with a frequency as low as ten per second.

2.0 Assumptions:

Data Flow:

- The analysis is concerned with the data traffic in one communication circuit. All data traffic will pass one way through this communications circuit. The server(s) will be on one side of this circuit and the workstation(s) will be on the other side.

Hardware and Architecture:

- The hardware will be selected from the items called out in the System Design Description (SDD).
- The video traffic will originate at a video server. This server will conform to the generic specifications for servers given in the SDD.
- The NSM traffic will originate at an NSM server. This server will conform to the generic specifications for servers given in the SDD.
- The ATM switch to which the servers are connected will be a FORE ASX-200BX, or one with characteristics very similar to a FORE ASX-200BX. The ATM switch to which the classroom workstations are connected will be a FORE ES3810, or one with characteristics very similar to a FORE ES3810.
- Two models, one with 51 users and one with 540 users, accurately represent the extrema of the configurations that will be fielded. (not valid- this ignores the single classroom site)

Data Traffic:

- The traffic from the workstations that produces responses from the servers is small enough to be ignored. Therefore, all modeled traffic originates at the server(s) location(s) and terminates at the classroom(s).
- It is assumed that all traffic is the result of class activity, except for an additional 3% of the total of all other traffic added for Network System Management (NSM) traffic. The value of 3% is taken from an SBIS investigation of NSM traffic loading.
- NSM traffic can be represented by messages transmitted to random workstations with the same basic time interval as all other traffic.

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- Average traffic will result from all workstations simultaneously receiving an “average” size message at a frequency of no less than one message per second.
- Worst case traffic will result from all workstations simultaneously receiving MPEG1 video messages from their video server at a frequency of no less than one message per second.
- Average message size is calculated from data given in a spreadsheet containing data on MOA Courseware. (Data for some classes was not used because of incomplete and / or inconsistent data.)
- A consistent procedure was used to calculate the total data traffic generated during the total duration of the class for each class. Then an average for all classes, weighted for class distance learning duration, was calculated.

Appendix C

Five Contributors to Bandwidth

The five functions performed in a classroom in the TADLP system that will use bandwidth are shown at the top of figure 1, with various means of implementation shown below each. The difference in the level of implementation for each use is an incremental increase in the amount of bandwidth required for each function when reading from the top to the bottom of each column.

Figure 1. Classroom Functions.

| A: Courseware | B: VTT | C: Collaboration | D: Simulation | E: Administration* |
|---|--------------------------|---|---|---|
| 1. <i>Overnight or Postal distribution to student</i> | 1. <i>TNET-like</i> | 1. <i>e-mail only</i> | 1. <i>single workstation</i> | 1. <i>manual – paper/fax</i> |
| 2. <i>Overnight or Postal distribution to large local DTAC (holds all courses)</i> | 2. <i>Computer based</i> | 2. <i>e-mail + audio collaboration</i> | 2. <i>multiple workstations; single classroom</i> | 2. <i>sneaker net (stand-alone terminal at DL site; needs formal interface agreement)</i> |
| 3. <i>central push to large local DTACs</i> | | 3. <i>e-mail + chat room</i> | 3. <i>multiple workstations; & classrooms</i> | 3. <i>full integration with student admin systems</i> |
| 4. <i>hybrid: common-use courses at local DTAC; all others pulled from course warehouse</i> | | 4. <i>e-mail + shared electronic whiteboard</i> | 4. <i>full SIMNET connectivity</i> | |
| 5. <i>no local DTAC; all courses pulled from central (virtual) repository</i> | | 5. <i>e-mail + shared applications</i> | | |
| | | 6. <i>workstation audio / video collaboration (same system as used in B2)</i> | | |

*Network Overhead was included with the Administration function for the purposes of this calculation:

Appendix D

Estimation of Expected Bandwidth

Bandwidth calculations using courseware media type to calculate average bandwidth

(values from the prior step or carried forward to the next step are shown as **bold italic**)

1. First, need to know averages for courseware functional type

| Course Breakdown in PerCent by Type Instruction | | | | | | | | | | | |
|---|--------|--------------|------------|--------------|---------|---------------|--------|---------------|-------|--------------|--|
| | Hrs | % | Hrs | % | Hrs | % | Hrs | % | Hrs | % | |
| | Paper | Paper | Video Tape | Video Tape | IMI | IMI | VTT | VTT | Other | Other | |
| Direct | 345.08 | na | 44.4 | na | 2825.56 | na | 882.96 | na | 343.2 | na | |
| Weighted* | na | 7.77% | na | 1.00% | na | 63.62% | na | 19.88% | na | 7.73% | |

weighted by classroom hours of instruction

Courseware functional types "IMI" and "Other" break down further into media types

| IMI by Media Type | | | Other by Media Type | | |
|-------------------|-------|---------------|---------------------|---------|---------------|
| type | IMI % | % @ IMI = | Media Type | Other % | % @ other % = |
| Streaming Video | 10% | 6.36% | Streaming Video | 10% | 1.73% |
| Text | 70% | 44.54% | Text | 70% | 5.41% |
| Images | 20% | 12.72% | Images | 20% | 1.55% |

Note (see assumptions):

Courseware functional type "Paper" is assumed to eventually be converted to Text.

Courseware functional type "Video Tape" is assumed to be converted to Streaming Video.

Courseware functional type "Other" includes Internet-based courseware.

2. All courseware media types are then summed to provide expected percentages of media types

(weighted by classroom hours of instruction)

| % By Media Type = | Type Instr + | IMI + | Other | Total |
|-------------------|---------------|---------------|--------------|----------------|
| Streaming Video | 1.00% | 6.36% | 0.77% | 8.13% |
| Text | 7.77% | 44.54% | 5.41% | 57.71% |
| Images | 0% | 12.72% | 1.55% | 14.27% |
| subtotal | | | | 80.12% |
| VTT | 19.88% | 0% | 0% | 19.88% |
| | | | | 100.00% |

3. Assumptions and Factors

- Courseware functional type "Paper" is assumed to eventually be converted to Text.
- Courseware functional type "Video Tape" is assumed to be converted to Streaming Video.
- VTT is considered separately.
- Bandwidth attributable to Text is not affected by courseware pre-positioning.
- Collaboration is not networked over the WAN in Phase II.
- Simulation is not networked over the WAN in Phase II.

g. Other Factors

| | |
|--|------|
| The number of seats per classroom is: | 17 |
| The number of VTT or collaboration streams per classroom is: | 1 |
| Expected usage is: | 100% |

based on:

| | | | |
|-------------------------------|------|------|---|
| Streaming Video Bandwidth is: | Mbps | 1.50 | the MPEG1 standard |
| Text Bandwidth is: | Kbps | 56 | download of a text only lesson in 100 sec * |

* See table 3-4 of Reference (f); an average text only lesson is sized at 895KiloBytes: (895KB*8B/b)/(100 sec) = 55.8Kbps

| | | | |
|---|------|-----|--|
| Images Video Bandwidth is: | Kbps | 800 | download of a 100KByte JPEG image in 1 sec |
| VTT Bandwidth is: | Kbps | 384 | the H.320 VTC standard |
| The percentage of courseware downloaded is: | 100% | | prepositioning factor = 0 |

| | |
|--------------|-----|
| Overhead is: | 15% |
|--------------|-----|

4. The media types are then weighted by bandwidth, and other factors are included

| | Media Bandwidth (Kbps) | Weighted % of Media | Kbps per seat | Mbps per classroom |
|------------------------------|------------------------|---------------------|---------------|---------------------------|
| Streaming Video | 1500 | 8.13% | 122.0 | 122.0 x 17 = 2.074 |
| Images | 800 | 14.27% | 114.2 | 114.2 x 17 = 1.941 |
| Text | 56 | 57.71% | 32.3 | 32.3 x 17 = 0.55 |
| Overhead - Images & Video | | 15.00% | 35.4 | 35.4 x 17 = 0.602 |
| Bandwidth / seat = | | 80.12% | 303.9 | |
| Seats / classroom = | | | 17.00 | |
| Use factor = | | | 100% | |
| Pre-positioning Factor = | | | 0.0 | |
| Bandwidth/classroom = | | | | 5.167 Mbps |

Appendix E Courseware Media Content Percentage

The functional proponent provided the following expected percentages of media content, and the lengths of the resident and distance learning portions of the courses being developed for distance learning during FY 1998. Weighted percentages of media, and other data was calculated from this information and is shown in the spreadsheet below:

| FY 98 Courses by Media Content Percentage | | | | | | | | | | | | | | | | |
|--|--------------|----------|-------|-------|-------------|-------|---------------|-------|------------|---------|------------|--------|--------------|--------|---------|--|
| The following data was derived from MOA Courseware | | | | | | | | | | | | | | | | |
| Assumption: | | Hrs/Wk = | | 40 | | | | | | | | | | | | |
| SCHOOL | Course | On-site | DL | Total | Hrs Text | %Text | Hrs SV | %S.V. | Hrs IMI | %IMI | Hrs VTT | %VTT | Hrs Other | %Other | %Total | |
| MEDCOM | 91B10R | 6 | 4 | 10 | 33.28 | 20.8 | 8 | 5 | 53.76 | 33.6 | 64.96 | 40.6 | 0 | 0 | 100 | |
| | 91B30(TT) | 5 | 5 | 10 | 25 | 12.5 | 10 | 5 | 91.8 | 45.9 | 73.2 | 36.6 | 0 | 0 | 100 | |
| | 91B40 | 2 | 5 | 7 | 20 | 10 | 10 | 5 | 60 | 30 | 90 | 45 | 20 | 10 | 100 | |
| | 91cfm40 | 2 | 5 | 7 | 0 | 0 | 0 | 0 | 100 | 50 | 80 | 40 | 20 | 10 | 100 | |
| FA (see note 1) | 13P10R | 7 | 3 | 7 | 6 | 5 | 1.2 | 1 | 40.8 | 34 | 72 | 60 | 0 | 0 | 100 | |
| | 2-6-c32-131a | 17 | 11 | 28 | 22 | 5 | 4.4 | 1 | 198 | 45 | 215.6 | 49 | 0 | 0 | 100 | |
| JFKSWC | 18B40 | 10 | 4 | 14 | 0 | 0 | 0 | 0 | 91.2 | 57 | 32 | 20 | 36.8 | 23 | 100 | |
| | 18C40 | 10 | 4 | 14 | 0 | 0 | 0 | 0 | 91.2 | 57 | 32 | 20 | 36.8 | 23 | 100 | |
| | 18D40 | 11 | 3 | 14 | 0 | 0 | 0 | 0 | 54 | 45 | 26.4 | 22 | 39.6 | 33 | 100 | |
| | 18E40 | 11 | 3 | 14 | 0 | 0 | 0 | 0 | 54 | 45 | 36 | 30 | 30 | 25 | 100 | |
| SSI | 71L10R | 5 | 6 | 11 | 0 | 0 | 0 | 0 | 280 | 100 | 0 | 0 | 0 | 0 | 100 | |
| | 71LF5 | 5 | 3 | 8 | 79.2 | 66 | 0 | 0 | 13.6 | 34 | 0 | 0 | 0 | 0 | 100 | |
| | 73C10R | 7 | 7 | 14 | 0 | 0 | 0 | 0 | 40 | 100 | 0 | 0 | 0 | 0 | 100 | |
| EN | 51B10R | 6 | 1 | 7 | 26.4 | 3 | 8.8 | 2 | 308 | 70 | 110 | 25 | 0 | 0 | 100 | |
| MP | 96BCD30 | 5 | 1 | 6 | 0 | 0 | 0 | 0 | 0 | 100 | 0 | 0 | 0 | 0 | 100 | |
| AV | 93C10R | 2 | 11 | 13 | 13.2 | 10 | 0 | 10 | 0 | 30 | 0 | 50 | 0 | 0 | 100 | |
| AR | 2-17-C22 | 13 | 5 | 18 | 40 | 20 | 0 | 0 | 160 | 80 | 0 | 0 | 0 | 0 | 100 | |
| USASMA | BSNCO | 0 | 2 | 2 | 1.6 | 2 | 0 | 0 | 16 | 20 | 38.4 | 48 | 24 | 30 | 100 | |
| MI | 96R10R | 4 | 1 | 5 | 0 | 0 | 0 | 0 | 32 | 80 | 8 | 20 | 0 | 0 | 100 | |
| CASCOM | 86M30 | 1 | 2 | 3 | 0 | 0 | 0 | 0 | 80 | 100 | 0 | 0 | 0 | 0 | 100 | |
| | 86M40 | 1 | 2 | 3 | 0 | 0 | 0 | 0 | 80 | 100 | 0 | 0 | 0 | 0 | 100 | |
| | 86M10R | 5 | 1 | 6 | 0 | 0 | 0 | 0 | 40 | 100 | 0 | 0 | 0 | 0 | 100 | |
| | 86H10R | 6 | 1 | 7 | 0 | 0 | 0 | 0 | 40 | 100 | 0 | 0 | 0 | 0 | 100 | |
| | 63B10R | 3 | 2 | 5 | 0 | 0 | 0 | 0 | 80 | 100 | 0 | 0 | 0 | 0 | 100 | |
| | 63B30 | 3 | 4 | 7 | 0 | 0 | 0 | 0 | 160 | 100 | 0 | 0 | 0 | 0 | 100 | |
| | 57E10R | 3 | 1 | 4 | 0 | 0 | 0 | 0 | 40 | 100 | 0 | 0 | 0 | 0 | 100 | |
| | 55B30 | 3 | 10 | 12 | 0 | 0 | 0 | 0 | 400 | 100 | 0 | 0 | 0 | 0 | 100 | |
| AVLOG | 67T10R | 8 | 1 | 9 | 2 | 5 | 2 | 5 | 6 | 15 | 4.4 | 11 | 25.6 | 64 | 100 | |
| SC | 31U30 | 3 | 1 | 4 | 0 | 0 | 0 | 0 | 25.6 | 32 | 0 | 0 | 54.4 | 68 | 100 | |
| | 31U40 | 3 | 1 | 4 | 2 | 0 | 0 | 0 | 24 | 30 | 0 | 0 | 56 | 70 | 100 | |
| IN | 11CMF30 | 3 | 2 | 5 | 43.2 | 54 | 0 | 0 | 36.8 | 46 | 0 | 0 | 0 | 0 | 100 | |
| | 11C30 | 3 | 2 | 5 | 7.2 | 9 | 0 | 0 | 72.8 | 91 | 0 | 0 | 0 | 0 | 100 | |
| | 11C40 | 2 | 2 | 4 | 24 | 30 | 0 | 0 | 56 | 70 | 0 | 0 | 0 | 0 | 100 | |
| | | | | | 345.08 | 7.77% | 44.4 | 1.00% | 2825.6 | 63.62% | 882.96 | 19.88% | 343.2 | 7.73% | 4441 | |
| | | | | | Hrs | % | Hrs | % | Hrs | % | Hrs | % | Hrs | % | %Total | |
| Courseware | Resident | DL | Total | | Text (1) | | Videotape (2) | | IMI | | VTT | | Other | | | |
| | 60% | 40% | | | Percentage | 7.77% | | 1.00% | | 63.62% | | 19.88% | | 7.73% | 100.00% | |
| | 6700.086 | 4441.2 | | | Hours | 345.1 | | 44.4 | | 2,825.6 | | 883.0 | | 343.2 | | |
| Notes: | | | | | | | | | | | | | | | | |
| (1) Paper based instruction was assumed to eventually be digitized to text based IMI for presentation | | | | | | | | | | | | | | | | |
| (2) Videotape based instruction was assumed to be eventually converted to streaming video based IMI for presentation | | | | | | | | | | | | | | | | |
| (3) "Other" includes Internet-based courseware | | | | | | | | | | | | | | | | |